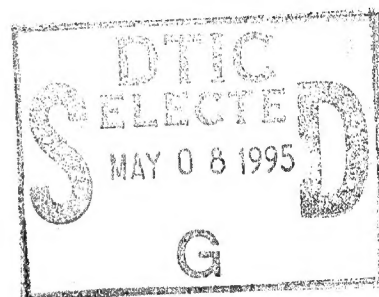


# THERMAL PERFORMANCE OF NAVY ANTI-EXPOSURE COVERALL TO DIFFERENT WATER EXPOSURE CONDITIONS



**NAVY CLOTHING AND TEXTILE RESEARCH FACILITY**

**NATICK, MASSACHUSETTS**

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## INTRODUCTION

The U.S. Navy Clothing and Textile Research Facility (NCTRF) evaluated a Navy standard (Coveralls, Anti-Exposure, MIL-C-29109B) and modified (Coveralls, Submarine Deck Exposure, MIL-C-29109) anti-exposure coverall to determine their thermal protection characteristics under different water exposure conditions. The principle differences between the standard and modified coveralls were the closures used in the wrist, ankle, and neck areas. The standard coverall is equipped with hook and loop tape fastener closures in the wrist and ankle areas and a neoprene foam flap closure secured by hook and loop tape fasteners in the neck area. The modified coverall was equipped with pneumatically inflatable closures in all of these areas.

This evaluation was undertaken because previous studies by the U.S. Coast Guard (1,2) and the Cord Group Limited (3) showed increased body cooling rates when similar protective clothing was employed in rough or agitated sea conditions compared to calm seas.

Testing of the two (2) coveralls was performed in the NCTRF immersion facility where a pressurized air system was used to create an agitated water flow condition. NCTRF's Thermal Manikin (TM) was employed with the coveralls to determine their Effective Thermal Insulation Resistance (ETIR) values (CLO) under calm and agitated water conditions.

The findings from this evaluation were as follows:

1. In calm water the thermal performance of the standard coverall was measurably better than the modified coverall evaluated in this study. The overall ETIR value over the coverall area was approximately 19% higher for the standard versus the modified coverall.
2. In agitated water there was a major reduction in thermal performance for both the standard and modified coveralls compared to calm water. The overall reductions in ETIR values from calm to agitated water were 84-89% over the coverall area and 78-87% below the neck region for the standard and modified coveralls, respectively. Survival times were shortened from 340 and 285 minutes in calm water to 85 and 70 minutes in agitated water for the standard and modified coveralls, because of these ETIR reductions.
3. Regional ETIR values for agitated water showed that most of the heat loss occurred through the hood and neck closure areas, demonstrating the ineffectiveness of these closures to restrict water entry into the coveralls.

## INTRODUCTION (CONTINUED)

4. Improved hood and neck closures are required to limit water entry into the coveralls. Using a cord tie-off, to better secure the neck area during this evaluation, reduced water entry significantly. With the cord tie-off, the reduction in ETIR values downstream of the neck region of the coverall were 57-58% between calm and agitated water. These reductions in ETIR values with the cord tie-off were 21-29% less than occurred with the standard and modified coveralls, respectively, downstream from the neck region. The benefit of this reduced loss in ETIR values was demonstrated by the longer survival times achieved in agitated water. Survival times increased to 140 and 120 minutes with the cord tie-off, compared to survival times of 85 and 70 minutes without it for the standard and modified coveralls, respectively.
5. Achieving proper freeboard and body orientation in the water is significant to the thermal performance of the coveralls in agitated water.

This report describes the test items and equipment used, the methods and procedures employed and presents, and discusses the thermal protection results obtained. Potential improvements are also discussed, conclusions presented, and recommendations are proposed to improve the thermal protection performance of the standard coverall in water exposure conditions.

## DESCRIPTION OF TEST ITEMS

The Navy's anti-exposure coverall was initially developed for submarine personnel performing deck watch and lookout duties in port and underway. Utilization of the coverall was subsequently extended to all ship types. The coverall was principally designed as a work garment which provides thermal protection to personnel performing deck duties in the cold-wet environmental conditions encountered at sea. The coverall was also required to provide buoyancy and thermal protection to cold water exposure as a result of accidental or emergency immersion.

Both coveralls tested (Figures 1 and 2), had a nylon outer shell fabric with a neoprene coating on the interior side to provide wind and rain protection, an interlining of Polyvinylchloride (PVC) closed cell foam for thermal protection and buoyancy characteristics, and a nylon taffeta lining to ease donning and doffing of the coverall. The PVC foam interlining was utilized in two (2) thicknesses. In the upper torso section the thickness was 0.635 cm. (0.25 in.) and in all other areas of the coverall the thickness was 0.318 cm. (0.125 in.). Both coveralls also had an attached hood with drawcord, a hook and loop tape fastener waist adjustment, and a front closure slide fastener with an interior protective flap that extended from the neck to the crotch.



## DESCRIPTION OF TEST ITEMS (CONTINUED)

The distinguishing feature between the two (2) coveralls were the closures. The standard coverall had a neoprene foam flap neck closure (SCNF) secured by hook and loop tape fasteners, and hook and loop tape fasteners in the wrist and ankle sections to secure the lower arm and leg sections of the coverall over the Navy cold-wet mittens and boots normally worn with the coverall. The modified coverall employed pneumatically inflated closures (MCP) in the neck, wrist, and ankle areas to provide flexibility in the degree to which the closures could be tightened by the wearer, depending upon the exposure conditions experienced. For the prototype coverall evaluated in this study, the pneumatic elements were standard medical blood pressure cuffs of different sizes which were secured to the coverall between the outer shell fabric and foam interlining. The coveralls tested were size large.

The cold-wet mittens (MIL-M-87033) employed with the coveralls (Figure 3) consist of a supported neoprene dipped outer shell and a removable polyurethane open-cell foam insulating liner covered by a nylon tricot knit fabric flame bonded to the polyurethane foam. The cold-wet boots (MIL-B-41816, Type I, Class 2) (Figure 4) utilize the double vapor barrier principle to achieve thermal protection. The outer and inner layers of the boot are made of rubber, while the interlining consists of fibrous insulation. The rubber layers are sealed to each other with adhesives to prevent the fibrous insulation from becoming wet. The boots have inherent buoyancy because of their sealed construction.

## DESCRIPTION OF TEST EQUIPMENT

1. **Immersion Facility.** The facility has a pool and an air chamber above the pool. The temperature of the air and water can be controlled independently, over a broad range, to simulate air/sea interface temperatures found around the world. Ambient air and water temperatures are measured with Yellow Spring Instruments (YSI) Series 400 thermistors. During the calm water condition, the water in the pool was circulated using the pool circulating and filtering system. This ensures a uniform water temperature and prevents a thermal boundary layer from developing near the outer surface of the coverall dressed TM. The water was recirculated at a rate of 39 cubic meters per hour (170 gallons per minute) resulting in a total recooling of the water every 41 minutes.

Water agitation was achieved with a compressed air source. The compressed air was released at a rate of two (2) standard cubic meters per minute (70 standard cubic ft. per minute) near the bottom surface of the pool through a perforated PVC pipe. The continuous expansion of the air as it passes vertically to the water surface displaces the water and creates a uniform flow of frothy water over and around the test coverall dressed TM. The surface current was 0.07 m/s (2.3 ft./s) (Figure 5). Under both water conditions the coverall dressed TM was constrained from moving to maintain the

## DESCRIPTION OF TEST EQUIPMENT (CONTINUED)

relative water flow at 0.07 m/s between the TM and the pool water. The flow direction was from the head to the feet of the TM. The manikin's orientation in the water provided a freeboard (vertical distance from the water surface to airways) of 11.4 cm (4.5 in.) in calm water (Figure 5).

2. **Thermal Manikin.** The TM (4) is constructed of 1.3 cm. thick cast aluminum and is representative of a fifty percentile man in size. The manikin has a body surface area of 1.8 m<sup>2</sup>, and through the control and data acquisition system used with the manikin, its surface temperatures can be controlled and measured independently in ten (10) body regions (head, torso, arms, legs, hands, and feet). These temperatures are measured using YSI 44906 thermistors, with three (3) sensors being utilized for each hand and foot, five (5) for each arm and leg, six (6) for the head, and fifteen (15) for the torso. The electrical power used in each region to maintain a constant surface temperature, is also controlled and measured. From this information, the ETIR value (CLO) of a test item worn by the manikin can be determined:

$$\text{ETIR (CLO)} = 6.45 (\text{SA})(T_s - T_a)/P$$

where:

- 6.45 = units constant
- SA = total or regional surface area, m<sup>2</sup>
- T<sub>s</sub> = mean total or regional surface temperature, degrees C
- T<sub>a</sub> = ambient temperature, degrees C
- P = total or regional electrical power required to maintain a constant surface temperature, W

## METHODS AND PROCEDURES

1. **Static Water Leakage Tests.** The water leakage from the hook and loop tape and pneumatic closures used in the wrist and ankle areas on the SCNF and MCP, respectively, was evaluated with the coveralls dressed on a manikin similar in size to the TM. The Navy standard cold-wet mittens and boots were also employed. Once the wrist and ankle closures were secured around the mittens and boots, respectively, water was poured into the arm and leg cavities with a hose. The degree of water leakage from the ankle and wrist closure sites was observed for each closure type.
2. **Thermal Manikin Tests.** The TM was dressed out in each coverall and with the Navy's standard cold-wet mittens and boots, and exposed to calm and agitated water conditions established in the pool. The underclothing worn were the Navy's cotton cold weather underwear, the standard chambray shirt and denim trouser work uniform, and the wool cushion sole socks. Each evaluation was performed in triplicate and the results averaged.

## METHODS AND PROCEDURES (CONTINUED)

For the calm water condition, the surface temperature of the TM was 35°C (95°F) with both the water and air temperatures controlled at 23.9°C (75°F). Under the agitated water condition, heat loss from the TM can be substantial with respect to the electrical power available for maintaining the TM's surface temperature. For these tests the air and water temperatures were the same, but the TM surface temperature was decreased until a temperature gradient was obtained where thermal equilibrium could be established.

During the TM testing for the agitated water condition, water was observed to be freely flowing into and out of the neck closure of both coveralls. Additional testing was conducted to determine if water entry at the neck closure could be effectively restricted. To accomplish this, the pneumatic neck closure on the Modified Coverall Pneumatic (MCP) was not inflated, and the neoprene foam flap neck closure on the Standard Coverall Neoprene Flap (SCNF) remained secured. A piece of cord was then tied securely around the neck area of each coverall to the TM. With the cord tie-off neck closure, the modified and standard coveralls were referred to as MCCT and SCCT, respectively.

3. **Survival Time.** Survival time in calm and agitated water for the different coverall configurations (SCNF, MCP, SCCT, and MCCT) was estimated using Shender's modified version of Wissler's mathematical simulation of human thermal behavior for whole body models (5,6). The inputs to the computer model were:

Water Temperature	- 10°C (50°F)
Initial Body Central Arterial Temperature	- 37°C (98.6°F)
Body Weight	- 75 kg (165 lbs.), 50th percentile
Mean Weighted Body Skinfold Thickness	- 9 mm, 50th percentile
Metabolic Rate	- 115w (100w sedentary + 15w work to maintain stability in water)
Regional ETIR Values	- CLO (Water Condition, Coverall Configuration)

Survival hypothermia was defined as a central arterial temperature of  $\geq 34^{\circ}\text{C}$  (93.2°F)(7), and was used as one of the end points. In Shender's modified version of the Wissler model, metabolic fatigue, where anaerobic heat generation capacity is lost, was also used as an end point. The end point, which occurred first, was used to estimate survival time.

## RESULTS

1. **Static Water Leakage Tests.** These tests showed no visual differences in water leakage between the hook and pile flap and pneumatic wrist and ankle closures on the standard and modified coveralls, respectively. Water only seeped out slowly from both types of closures indicating that water movement through these closures was limited and would not be the cause of excessive heat loss.
2. **TM Tests.** Because the principle purpose of this evaluation was the determination of the thermal performance of the coveralls, presentation of the results were limited primarily to those body regions associated with the coveralls, except for survival time determinations where hand and foot ETIR Values were included in model inputs.
  - A. Standard Coverall, Neoprene Flap Closure (SCNF) and Modified Coverall, Pneumatic Neck Closure (MCP) in Calm and Agitated Water.
    - a. Overall ETIR Values (Tables I and II).

For the calm water condition, the overall ETIR value for the coverall area was measurably higher (19%) for the SCNF compared to the MCP, 0.44 versus 0.37 CLO respectively (Tables I and II) and essentially similar below the neck region (Table II). For the agitated water condition, the overall ETIR values were substantially reduced compared to the calm water condition, 0.07 and 0.04 CLO over the coverall area (Tables I and II), and 0.09 and 0.05 CLO below the neck region (Table II) for the SCNF and MCP, respectively.

- b. Regional ETIR Values (Table I, Figure 6).

For the calm water condition, the regional ETIR values for the SCNF were higher than the MCP ranging from 24% higher in the leg areas to 9% higher in the arm areas. For the agitated water condition, the regional ETIR value for the head area was similar and essentially zero for the SCNF and MCP. Differences in regional ETIR values between the SCNF and MCP for the other body regions (torso, arms, and legs) were small, 0.04 CLO or less.

## RESULTS (CONTINUED)

- c. Reduction in Regional and Overall ETIR Values Between the Calm and Agitated Water (Table III).

Reductions in regional ETIR values in agitated water were substantial compared with values in calm water. The regional and overall reductions in ETIR values were similar in degree for both the SCNF and MCP for the coverall area. Reductions in regional ETIR values for the SCNF ranged from 95% for the head area to 58% for the leg areas, with an overall loss of 84% for the coverall area and 78% for the below neck region. For the MCP, reductions in regional ETIR values ranged from 97% for the head area to 62% for the leg areas, with an overall loss of 89% for the coverall area and 87% below the neck region. The overall reduction in ETIR value below the neck region was 11% less for the SCNF compared to the MCP.

- d. Survival Times (Table IV).

For the calm water condition, survival time was 19% higher for the SCNF compared to the MCP, 340 versus 285 minutes, respectively. For the agitated water condition, survival time was substantially reduced compared to the calm water condition, 85 and 70 minutes, respectively, for the SCNF and MCP.

- B. Standard and Modified Coverall with Cord Tie-off Neck Closure (SCCT and MCCT) in Calm and Agitated Water.

- a. Overall ETIR Values (Tables I and II).

For the calm water condition, the overall ETIR value was somewhat higher (21%) for the SCCT, 0.46 versus 0.38 CLO for the MCCT for both the coverall area and the below neck region (Tables I and II). For the agitated water condition, the overall ETIR values were substantially reduced compared to the calm water condition, 0.11 and 0.10 CLO over the coverall area (Tables I and II) and 0.20 and 0.16 CLO below the neck region (Table II) for the SCCT and MCCT, respectively.

## RESULTS (CONTINUED)

### b. Regional ETIR Values (Table I, Figure 7).

For the calm water condition, the regional ETIR values for the SCCT were higher or equivalent to the MCCT, ranging from 33% higher in the torso area to 3% higher in the arm areas. For the agitated water condition, the regional ETIR values for the head area were similar and essentially zero for the SCCT and MCCT. Differences in regional ETIR values were small, 0.03 CLO or less for the arm and leg areas, and moderate, .09 CLO in the torso area.

### c. Reduction in Regional and Overall ETIR Values Between the Calm and Agitated Water Conditions (Table III).

Reductions in regional ETIR values in agitated water were substantial compared to calm water. The regional ETIR reductions in all areas except the legs were of the same degree, and the overall reductions were similar for the SCCT and MCCT for the coverall area and the below neck region. Reductions in regional ETIR values for the SCCT ranged from 95% for the head area to 51% for the leg areas with an overall loss of 76% for the coverall area and 57% below the neck region. For the MCCT regional ETIR, reductions ranged from 94% for the head area to 32% for the leg areas, with an overall loss of 74% for the coverall area and 58% below the neck region.

### d. Survival Times (Table IV).

For the calm water condition, survival time was 24% higher for the SCCT compared to the MCCT, 360 versus 290 minutes, respectively. For the agitated water condition, survival time was substantially reduced compared to the calm water condition, 140 and 120 minutes, respectively, for the SCCT and MCCT. Compared to the SCNF and MCP the survival times for the SCCT and MCCT were 65-71% higher with the SCCT having the longest survival time (140 min.).

## DISCUSSION OF RESULTS

1. **SCNF and MCP.** The SCNF performed better than the MCP in calm water and similar to the MCP in agitated water, showing higher or equivalent ETIR values for both water conditions (Table I, Figure 6). Both coveralls provided limited thermal protection in agitated water, having similar overall reductions in ETIR values for the coverall area compared to calm water, 84% for the SCNF and 89% for the MCP, respectively (Table III). For the below neck region, the overall loss in ETIR values for the SCNF was 11% less than the MCP (Table III). The maximum reductions in regional ETIR values in agitated water versus calm water were in the head and torso areas (95% head and 88% torso for the SCNF, and 97% head and 94% torso for the MCP). Survival times were shortened from 340 and 285 minutes, respectively, for the SCNF and MCP in calm water to 85 and 70 minutes in agitated water (Table IV).

The poor performance of both coveralls in agitated water appears to have been caused primarily by the ineffectiveness of the hood and neck closures of both coveralls to limit water leakage into the coveralls when the agitated water flushed over the exposed facial region of the head and coverall neck closures. The low ETIR values measured in the head and torso areas indicate substantial and direct water entry into both the head and torso areas of both coveralls (Table III and Figure 7). The continuous entry of water into the head and neck areas of both coveralls established a second heat loss path. The normal heat flow path was from the TM surface through the clothing to the water. This second path was caused by the internal flow of water into the various regions of the coverall. The water flowing internally absorbs heat directly from the TM surfaces and eventually dissipates this heat energy to the external water either by direct leakage into the external water or by convection currents.

2. **SCCT and MCCT.** Incorporating the cord tie-off neck closure on both coveralls as a replacement for the neoprene flap and pneumatic neck closures, improved the thermal protective performance of the coveralls in agitated water, as indicated, by a lower reduction in ETIR values overall and regionally, except for the head area where the neck closure would have no influence (Table III and Figures 6 and 7). However, the reductions in ETIR values were still quite high. The overall loss in ETIR values between the calm and agitated water were 76% and 74% for the coverall area and 57% and 58% below the neck region for the SCCT and MCCP, respectively (Table III). Survival times were shortened from 360 and 290 minutes, respectively, for the SCCT and MCCT in calm water to 140 and 120 minutes in agitated water (Table IV).

The overall loss in ETIR value below the neck region was 21 and 29% less for the SCCT and MCCT compared to the SCNF and MCP, respectively, and survival times were at least 65% longer with the SCCT and MCCT compared to the SCNF and MCP.

## DISCUSSION OF RESULTS (CONTINUED)

This indicates that most of the reduction in overall ETIR values and associated survival times was caused by the direct heat loss from the head facial area to the water flowing over it, and the inadequacy of the hood drawcord closure to limit water entry into the other sections of the head area. This water eventually found its way through the neck area closure to the other body regions.

3. **Potential Improvements.** The Navy's anti-exposure coverall is primarily a work suit with properties that provide buoyancy and thermal protection to wearers in accidental water immersion. It is not an immersion suit designed specifically for "abandon ship"-type scenarios.

It has been noted in this evaluation that extensive reductions in ETIR values and associated survival times occurred in agitated water because of significant water leakage through the hood and neck closures of the coveralls. Overcoming these problems is not easy. Designing suitable hood and neck closures for immersion suits has also been found to be a difficult problem to solve (8).

To improve the thermal protection of the Navy's standard anti-exposure coverall (SCNF) in agitated or rough waters, the following needs to be considered:

### A. Freeboard.

The orientation of the dressed manikin in the pool created a freeboard of 11.4 cm. (4.5 in.) in calm water, which was reduced to zero by the agitated water. The 11.4 cm. value was essentially equivalent to the minimum requirement of 12 cm. (4.7 in.) stated in the Safety of Life at Sea (SOLAS) regulations (8). The SOLAS regulations for immersion suits when used with a life jacket require, in addition to the freeboard requirement, that the body be inclined backward at an angle of between 20° and 50° from a vertical position. In this evaluation, the orientation of the dressed TM was approximately 80° from a vertical position, and no life jacket was worn to enhance the flotation angle.

The use of the Navy's cold-wet boot with the coveralls contributed to the lack of adequate freeboard and proper body orientation. The boots have substantial buoyancy preventing the legs from dropping lower into the water. The boot needs to be removed on or prior to entering the water, or if equipped with an air bleed valve, as in the latest version of the specification for the boots, the valve could be opened to allow water entry into the sealed area of the boots with resulting loss in buoyancy of the boots. A neoprene foam sock or similar item could be used to keep the feet warm, although the lack of insulation to the feet does not influence survival time (8).



## DISCUSSION OF RESULTS (CONTINUED)

Increasing the thickness of the PVC foam in the frontal and rear areas of the upper torso of the coverall and the obvious use of the various Navy life preservers with the coverall, would help in achieving more freeboard and proper orientation in the water.

### B. Closures.

It is difficult to design effective closures in the head and neck areas of work garments because of the discomfort they cause. The use of pneumatic closures similar to those evaluated in this study were a potential solution to the discomfort problem. They could remain disabled when working in the coverall and be activated manually or automatically in accidental immersion. Improvements to the design employed, which was essentially a quick look concept using off-the-shelf medical blood pressure cuffs, should be considered. The use of the cord tie-off neck closure showed significant improvement could be achieved if the gap around the neck area of the coverall was closed effectively. The relationship of the current hood to the neck region where the hood is attached around the neck opening, accounts in large measure for the loss in thermal protection. The use of a collar around the neck opening with the hood attached externally to the collar should reduce direct water entry. However, the current zipper frontal closure on the coverall must be extended up to the underside of the chin to close the gap between the neck and the collar. The collar would be secured around the neck with a hook and loop tape fastener.

The hood needs some type of resilient foam material attached around its inner periphery to provide a more secure interface between the hood and the head than presently exists.

### C. Other Comments.

Achieving proper freeboard and body orientation is also significant to the thermal performance of the coveralls in agitated water. Considering the importance of the anti-exposure coverall to the cold-wet protection required shipboard, further work should be initiated to overcome or to substantially reduce the deficiencies found in this study.

## CONCLUSIONS

1. In calm water the thermal performance of the standard coverall was measurably better than the modified coverall evaluated in this study. The overall ETIR value over the coverall area was approximately 19% higher for the standard versus the modified coverall.
2. In agitated water there was major reduction in thermal performance for both the standard and modified coveralls as compared to their performance in calm water. The overall reductions in ETIR values from calm to agitated water were 84% and 89% over the coverall area and 78% and 87% below the neck region for the standard and modified coverall, respectively. Survival times were shortened from 340 and 285 minutes in calm water to 85 and 70 minutes in agitated water for the standard and modified coveralls because of these ETIR reductions.
3. Regional ETIR values for agitated water showed that most of the heat loss occurred through the hood and neck closure areas, demonstrating the ineffectiveness of these closures to restrict water entry into the coveralls.
4. Improved hood and neck closures are required to limit water entry into the coveralls. Using a cord tie-off to better secure the neck area during this evaluation reduced water entry significantly. With the cord tie-off, the reduction in ETIR values downstream of the neck region of the coverall were 57% and 58% between calm and agitated water. The reduction in ETIR values with the cord tie-off were 21-29% less than occurred with the standard and modified coveralls, respectively, downstream from the neck region. The benefit of this reduced loss in ETIR values was demonstrated by the longer survival times achieved in agitated water. Survival times increased to 140 and 120 minutes with the cord tie-off compared to survival times of 85 and 70 minutes without it for the standard and modified coveralls, respectively.
5. Achieving proper freeboard and body orientation in the water is significant to the thermal performance of the coveralls in agitated water.

## RECOMMENDATIONS

1. **Increase Freeboard.** By maintaining the frontal area of the head and neck areas above the water, the ineffectiveness of the hood and neck closures to limit water penetration into the coveralls could be substantially reduced. Increasing the thickness of the PVC foam material used in the upper torso area of the coveralls, discarding the cold-wet boot in the water, and the proper wearing of a life preserver will help to achieve the increased freeboard and proper body orientation needed in the water.

## RECOMMENDATIONS (CONTINUED)

2. **Closures.** Consider the use of a collar on the coverall interior to the hood that can be zipped up to the underside of the chin and then secured with a hook and pile tape fastener, and a resilient foam seal around the interior periphery of the hood to reduce the substantial water entry that currently occurs in these areas.
3. **Evaluation Protocol.** A standard protocol for evaluating anti-exposure coveralls or similar items using the thermal manikin or human volunteers needs to be developed. Different results can be obtained, depending on the ancillary protective equipment and clothing worn with the coveralls, the orientation of the manikin to the water flow and to the water surface, and the relative flow rate between the manikin and the water.

**TABLE I. Effective Thermal Insulation Resistance (ETIR) Values (CLO) for the Standard and Modified Coveralls in Calm and Agitated Water for Different Neck Closures.**

Water Cond	Cov/Neck Closure	ETIR						Overall	
		Region							
		Head	Torso	Arms	Legs	Hands	Feet	Cov <sup>1</sup>	Body <sup>2</sup>
Calm	SCNF	0.39	0.60	0.35	0.36	0.19	0.57	0.44	0.40
	MCP	0.32	0.52	0.32	0.29	0.19	0.49	0.37	0.35
	SCCT	0.43	0.65	0.35	0.37	0.18	0.60	0.46	0.42
	MCCT	0.33	0.49	0.34	0.31	0.25	0.47	0.38	0.37
Agitated	SCNF	0.02	0.07	0.07	0.15	0.15	0.50	0.07	0.07
	MCP	0.01	0.03	0.06	0.11	0.15	0.43	0.04	0.04
	SCCT	0.02	0.24	0.16	0.18	0.17	0.48	0.11	0.13
	MCCT	0.02	0.15	0.13	0.21	0.16	0.43	0.10	0.11

1. Coverall: Head, Torso, Arms, and Legs
2. Body: Head, Torso, Arms, Legs, Hands, and Feet

**TABLE II. Overall Effective Thermal Insulation Resistance (ETIR) Values (CLO) for the Various Coverall/Closure Arrangements in Calm and Agitated Water With and Without the Head Region Included.**

<u>Water Condition</u>	<u>Coverall/Neck Closure</u>	<u>Overall ETIR</u>	
		<u>Coverall Region<sup>1</sup></u>	<u>Below Neck Region<sup>2</sup></u>
Calm	SCNF	.44	.40
	MCP	.37	.38
	SCCT	.46	.46
	MCCT	.38	.38
Agitated	SCNF	.07	.09
	MCP	.04	.05
	SCCT	.11	.20
	MCCT	.10	.16

<sup>1</sup> Coverall Region - Head, Torso, Arms, and Legs

<sup>2</sup> Below Neck Region - Torso, Arms, and Legs

**TABLE III. Percentage Reduction in Regional and Overall Effective Thermal Insulation Resistance (ETIR) Values (CLO) Between Calm and Agitated Water Conditions for Different Neck Closures With and Without the Head Region Included.**

<u>Cov/Neck Closure</u>	<u>TM Region</u>				<u>Overall ETIR</u>	
	<u>Head</u>	<u>Torso</u>	<u>Arms</u>	<u>Legs</u>	<u>Coverall Region<sup>1</sup></u>	<u>Below Neck Region<sup>2</sup></u>
SCNF	95	88	80	58	84	78
MCP	97	94	81	62	89	87
SCCT	95	63	54	51	76	57
MCCT	94	69	62	32	74	58

<sup>1</sup> Coverall Region - Head, Torso, Arms, and Legs  
<sup>2</sup> Below Neck Region - Torso, Arms, and Legs

**TABLE IV. Survival Times for the Various Coverall/Closure Arrangements in Calm and Agitated Water for Full Body.**

<u>Water Condition</u>	<u>Coverall/Neck Closure</u>	<u>Survival Time</u> (min.)	<u>Arterial Temperature</u> (°C)	<u>End Point</u>
Calm	SCNF	340	34.4	MF <sup>1</sup>
	MCP	285	34.4	MF
	SCCT	360	34.5	MF
	MCCT	290	34.4	MF
Agitated	SCNF	85	34.0	AT <sup>2</sup>
	MCP	70	34.0	AT
	SCCT	140	34.0	AT
	MCCT	120	34.0	AT

<sup>1</sup> MF - Metabolic Fatigue

<sup>2</sup> AT - Arterial Temperature



FIGURE 1. Standard Anti-Exposure Coverall, MIL-C-29109B, SCNF.





**FIGURE 2.** Modified Anti-Exposure Coverall, MIL-C-29109, Pneumatic Closures Shown for Wrist and Ankle Areas, MCP.



**FIGURE 3. Cold-Wet Mittens, MIL-M-87033.**



**FIGURE 4.** Cold-Wet Boots, MIL-B-41816, Type I, Class 2.

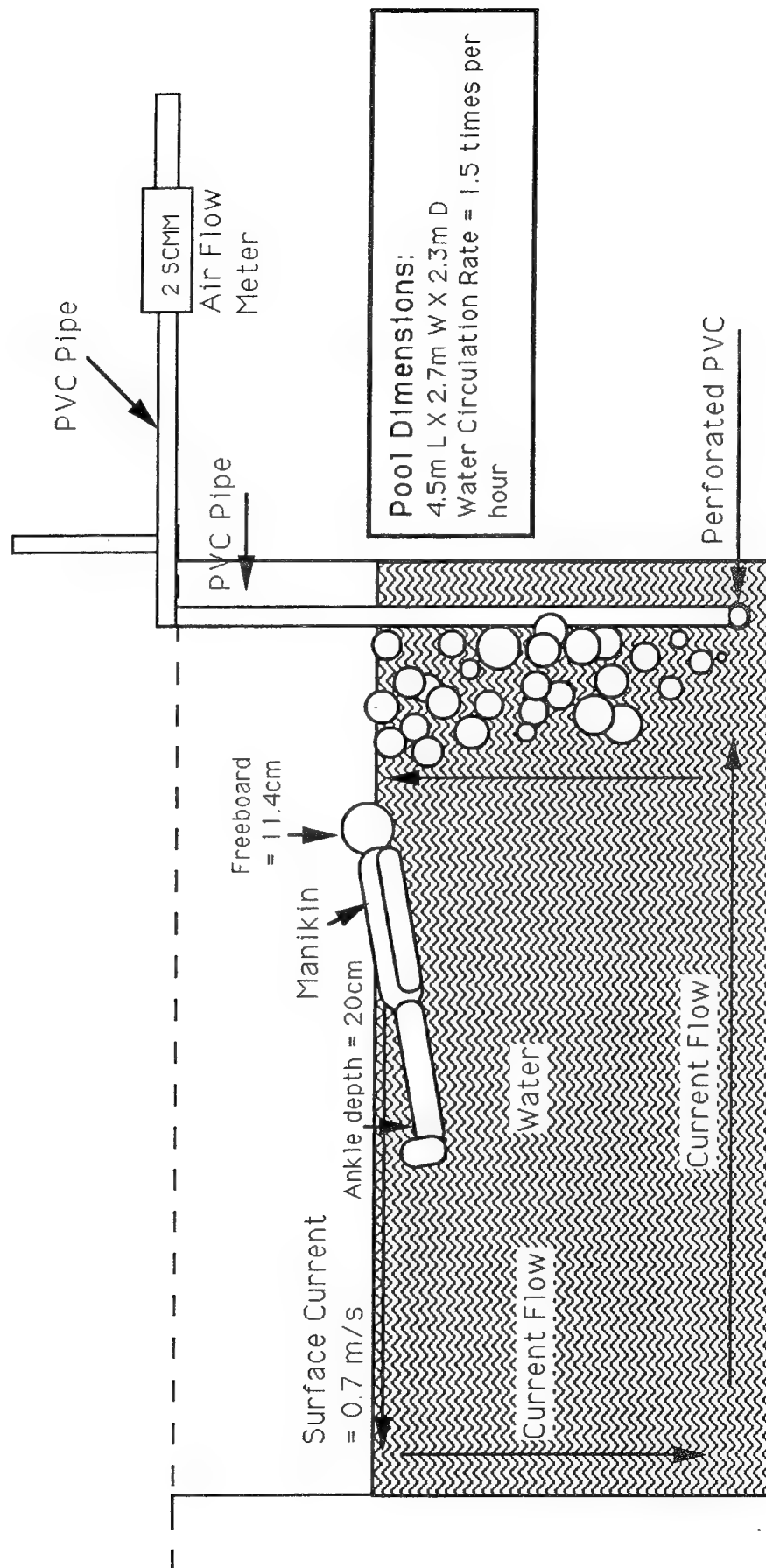


FIGURE 5. Water Agitation System.

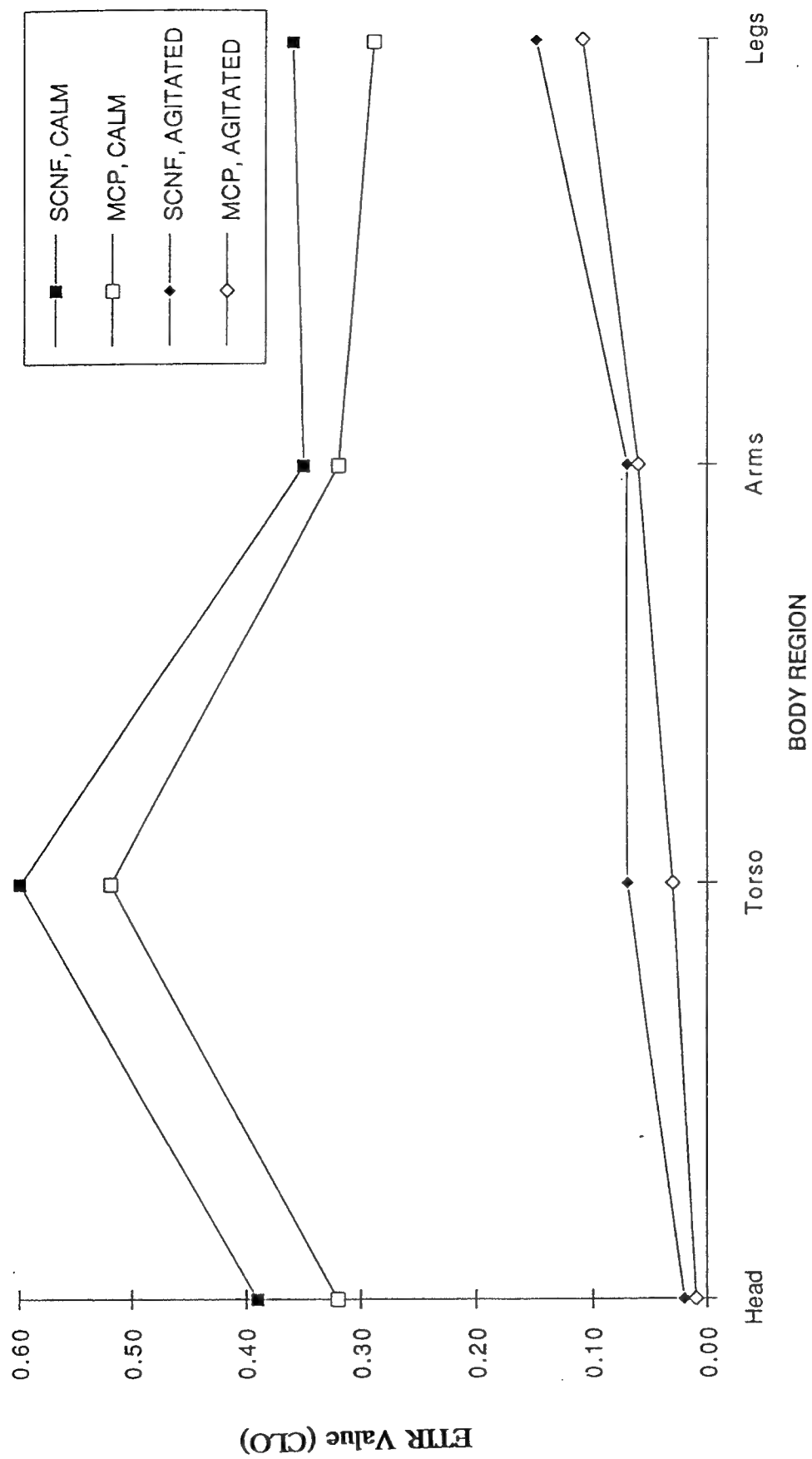


FIGURE 6. Effective Thermal Insulation Resistance (ETIR) Values (CLO) by Region for the SCNF and MCP in Calm and Agitated Water.

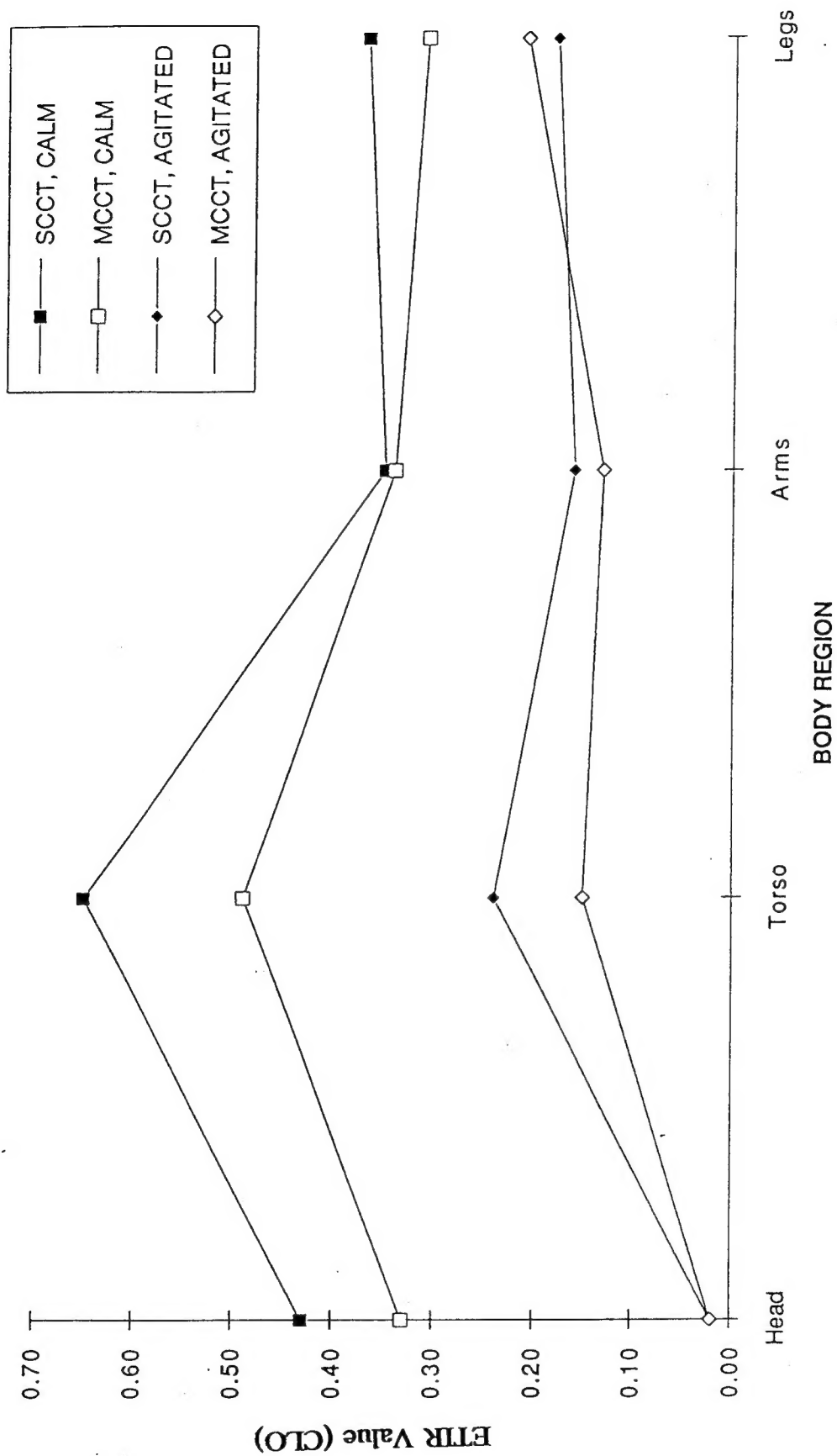


FIGURE 7. Effective Thermal Insulation Resistance (ETIR) Values (CLO) by Region for the SCCT and MCCT in Calm and Agitated Water.

## REFERENCES

1. Steinman, A. M., M. Nemiroff, J. Hayward, and P. Kubilis. A comparison of the protection against immersion hypothermia provided by Coast Guard Anti-Exposure Clothing in calm versus rough seas. U. S. Coast Guard Report No. CG-D-17-85, National Technical Information Service, Springfield, Virginia, 1985.
2. Steinman, A. M. and P. S. Kubilis. Survival at sea: The effects of protective clothing and survivor location on core and skin temperatures. U. S. Coast Guard Report No. CG-D-26-86, National Technical Information Service, Springfield, Virginia, 1986.
3. The Cord Group Limited. Report on the human and manikin comparison to determine a thermal criteria for the marine anti-exposure work suit system standard. February 1988.
4. Richardson, D. C. and N. F. Audet. A Ten-Zone Therman Manikin for Evaluating Personnel Protective Garments in Cold Areas and Water Immersion Environments, ASME Publication 80-WA10CE-B, 1980.
5. Shender, B.S., Modified Wissler Model. Naval Air Warfare Center, Warminster, PA.
6. Wissler E. H., Mathematical Simulation of Human Thermal Behavior Using Whole Body Models. In: Shitzer A., Eberhart R., eds. Biomedical Heat Transfer. New York: Plenum Press. 1985: 325-73.
7. Nunneley S. A., E. H. Wissler, J. R. Allan. Immersion Cooling: Effect of Clothing and Skinfold Thickness. Aviation Space Environmental Medicine. 1985; 56: 1177-82.
8. Research Study Group 7 on Bio-Medical Aspects of Military Protective Clothing, Handbook on Clothing, Chapter 8, Immersion Suits.

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